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Statistical Regularities of Alumina Fragmentation under Uniaxial Compression at Room and Liquid Nitrogen Temperatures

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Abstract. Uniaxial compression tests of cylindrical alumina samples were carried out at room and liquid nitrogen temperatures. An increase in the fracture toughness of samples deformed at low temperature was accompanied by the intensification of fragmentation. Fragment area distribution and fragment mass distribution were built for both temperatures. The first inflection points on the graphs testify to the presence of structural scaling, which governs the fragmentation of alumina samples.

INTRODUCTION

It has been shown that the mechanical properties of human dentin under uniaxial compression are sensitive to the experiment temperature [1-3]. At liquid nitrogen temperature (77 K), compression strength and elastic deformation of dentin were higher than these parameters at room temperature and, vice versa, at liquid nitrogen temperature the plasticity of dentin was very small in comparison with room temperature [2]. This effect is explained by the contribution of bioorganic phase, including collagen fibers, into the plastic deformation of dentin at room temperature, which, however, diminishes at 77 K. Hence, the inorganic phase must play an important role in the mechanical behavior of dentin at low temperatures [2]. In this paper, the mechanical properties of human dentin are compared with an intrinsically brittle material having 10 % of porosity (plasma spraying alumina) under the same deformation conditions. We have complemented the work with fragmentation analysis in order to envisage the effect of structural parameters on ceramic fracture at different temperatures.

EXPERIMENT

The preparation of cylindrical samples involves cutting the samples from an aluminum oxide billet by a diamond saw and their mechanical polishing in order to exclude defects from the lateral surfaces. Ceramics was produced by the plasma spraying deposition technique (Simteck, Ekaterinburg).

Uniaxial compression of the samples was carried out with a Shimadzu AGX-50kN testing machine. A hand-made foam device was used for experiments in liquid nitrogen. In these experiments, both upper and lower punches were immersed in liquid nitrogen for the minimization of temperature gradients in the sample. Loading curves were registered; sample fragments were saved after the experiment for the construction of fragmentation statistics for both experimental conditions (at room temperature and in a liquid nitrogen medium).

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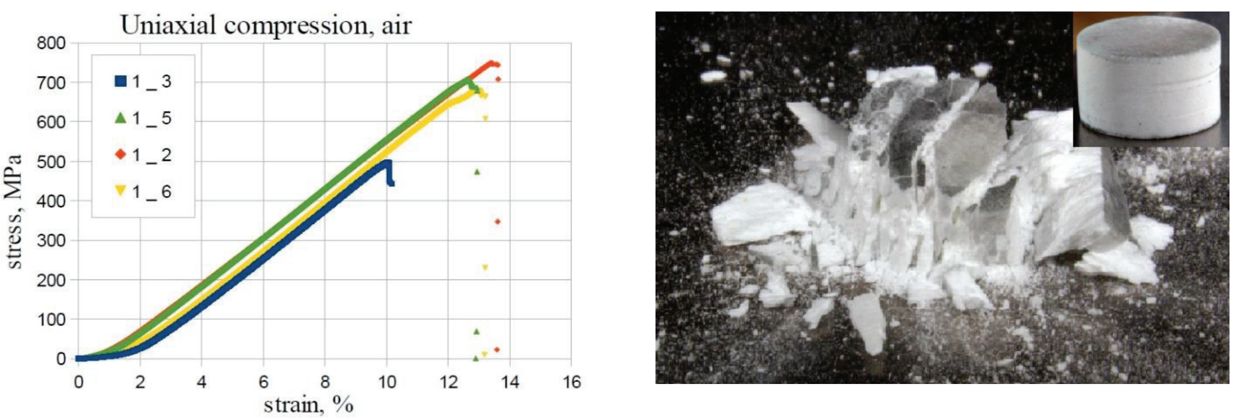
Fragmentation statistics was investigated by the determination of cumulative fragment size distribution, which means the relationships between the number of fragments with the area/mass larger than a prescribed value, and the area/mass of the fragment. Fragment mass was measured by weighing each fragment on the electronic balance HR-202i (the precision of the balance was 10^{-4} g and its minimum weight was 10^{-3} g). Large fragments were weighed separately and small ones were passed through a set of sieves. After weighing, fragments from each sieve were scanned with a Hyrox optical microscope in the transmission regime for getting images of their projection area. Thus, for each sample there was a set of loading curves and statistics of fragment distributions in terms of mass and area. Besides, we have checked the number of fragments in each sieve, as it was done in [4]. This experimental data allowed us to demonstrate the difference between aluminum oxide ceramics fragmentation at room temperature and that in liquid nitrogen.

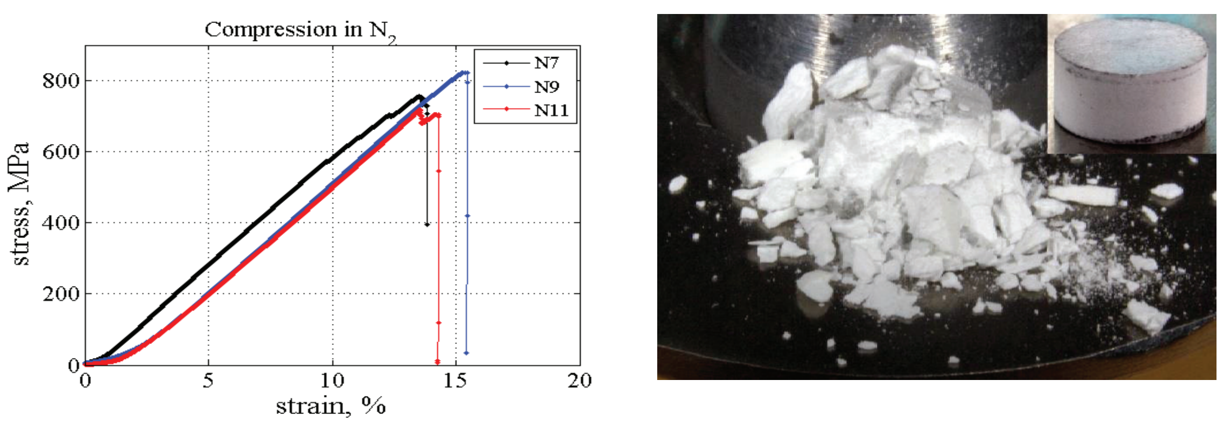
RESULTS

Deformation curves for experiments in air at room temperature and in liquid nitrogen and corresponding photos of samples before and after loading are presented in Fig. 1 and 2 respectively. For experiments made at room temperature, fracture occurs at 712 ± 60 MPa (Fig. 1), whereas in liquid nitrogen fracture toughness was 765 ± 90 MPa (Fig. 2). Maximum strain before fracture was found to be almost the same for the experiment in air and that in liquid nitrogen (14 % and 13 % respectively).



(a) (b)

FIGURE 1. The deformation curve (a) and photos of the sample before and after loading at room temperature in the air atmosphere



(a) (b)

FIGURE 2. The deformation curve (a) and photos of the sample before and after loading in a liquid nitrogen medium

Analysis of the fragmentation of aluminum oxide ceramics has revealed a more intensive character of the fracture processes in liquid nitrogen, which reflects in a greater number of fragments in each sieve (Fig. 3). Besides, there is a spatial scale at which the number of fragments is significantly higher (sieve cell size is 0.4 mm for both experimental conditions).

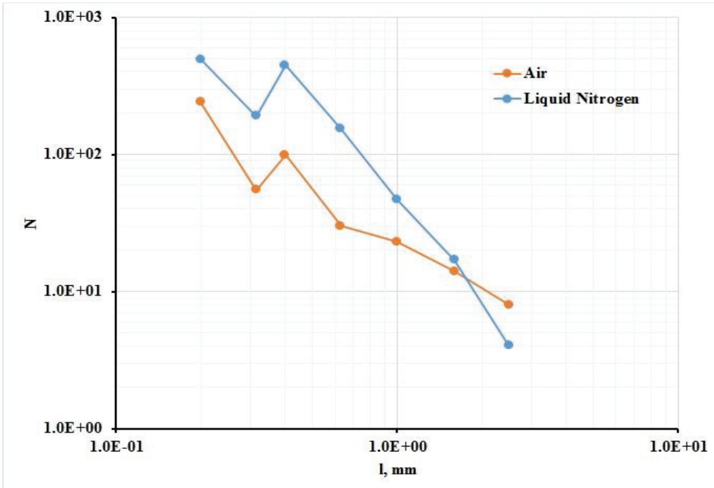


FIGURE 3. Fragment size distribution for samples deformed at room temperature and in liquid nitrogen in terms of sieve cell size and the number of fragments in each sieve

Figure 4 presents a log-log plot of fragment mass distribution for samples deformed at room temperature (curve 1) and in liquid nitrogen (curve 2). Here, the x-axis is a logarithm of fragment mass and the y-axis is a logarithm of the number of fragments with a mass larger than a prescribed value. For both experiment temperatures, fragment mass distribution can be approximated by the power law with different exponents. Also, deformation in liquid nitrogen results in a greater number of fragments with smaller mass in comparison with loading at room temperature.

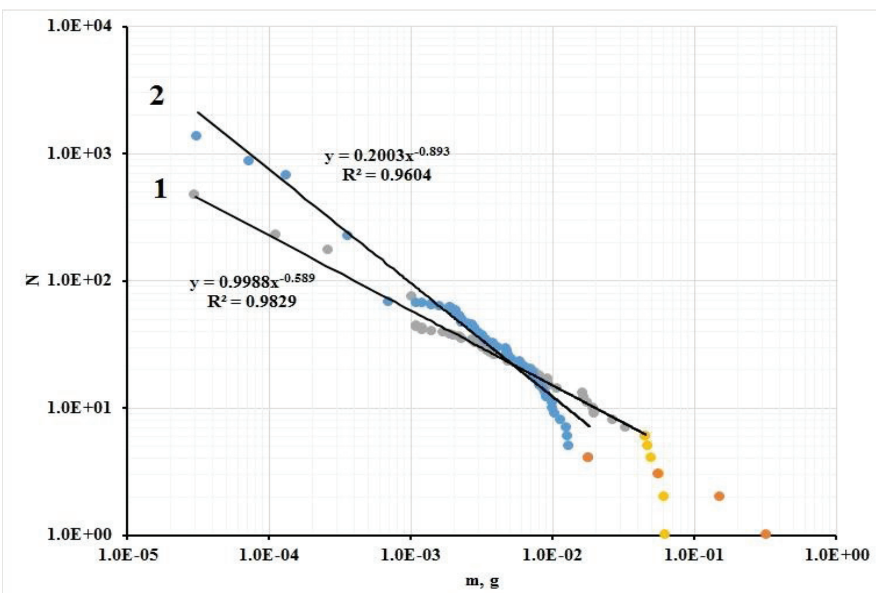


FIGURE 4. Fragment mass distribution for samples deformed at room temperature (1) and in liquid nitrogen (2) and their power law approximation

Figure 5 presents a log-log plot of fragment area distribution for samples deformed at room temperature (curve 1) and in liquid nitrogen (curve 2). Here, the logarithm of the fragment area values is plotted over the x-axis and the logarithm of the number of fragments with the area larger than the prescribed value is plotted over the y-axis. For the experiment in air at room temperature, the most part (69 %) of the fragment area distribution curve can be approximated by a single line in log-log coordinates. For the experiment in liquid nitrogen, this curve is shifted to bigger scales, and its approximation can be described by two power law functions with different slopes.

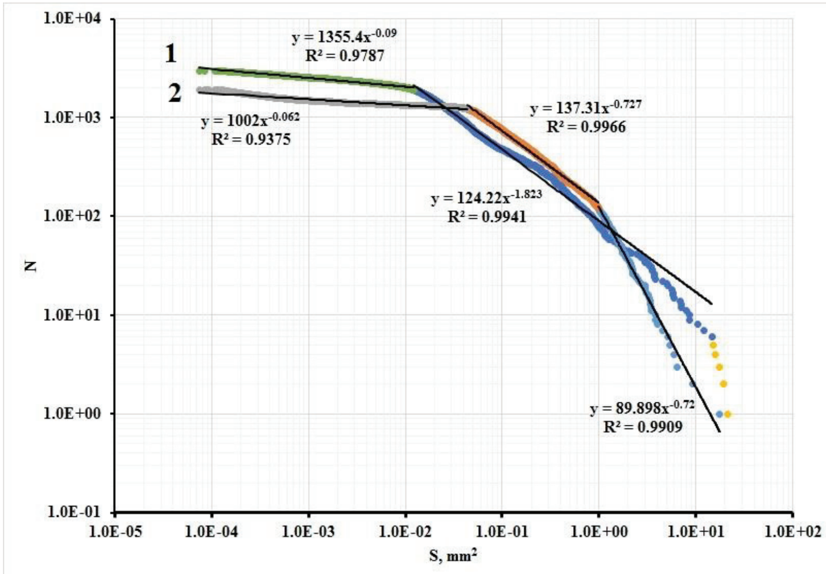


FIGURE 5. Fragment area distribution for samples deformed at room temperature (1) and in liquid nitrogen (2) and their power law approximation

DISCUSSION

Uniaxial compression of cylindrical specimens prepared from aluminum oxide ceramics was carried out at room temperature and in liquid nitrogen. The increase of the fracture toughness of ceramics deformed at low temperature is accompanied by the intensification of the fragmentation process. Fragment area and mass distributions were constructed for both experimental conditions. First inflection points on the graphs testify to the presence of structural scale, which governs the fragmentation of the material.

ACKNOWLEDGMENTS

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